Assembly of Dissimilar Aluminum alloys for automotive applications

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Project ID # mat134

VTO/DOE Annual Merit Review Meeting, June 20, 2018

Project Overview

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Project Timeline

- Start: Q4FY2017
- Finish: Q4 FY2019
- 38% Complete

Barriers

- Scientific understanding of relationships between process parameters, interface geometry and resulting joint property in Lap welding is limited.
- Increased joining speed is needed for process commercialization.

Budget

- Total project funding: $1M
  - DOE: $500k
  - Industrial cost share: $500k
- FY17 DOE Funding: $500k
- Industry Cash: $50k

Partners

- **Lead**

  PNNL
- **OEM**

  Honda R&D Americas, Inc.
- **Supplier**

  Arconic, Inc.

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HONDA

Honda R&D Americas, Inc.

ARCONIC

Innovation, engineered.

Relevance

- **Overall Objective:**

  Develop joining technology needed to demonstrate fabrication of Aluminum alloy assemblies to enable automotive lightweighting for high volume industrial commercialization. (addressing technology gap identified by USDRIVE Roadmap (Sec. 5.1) 2017) [1]

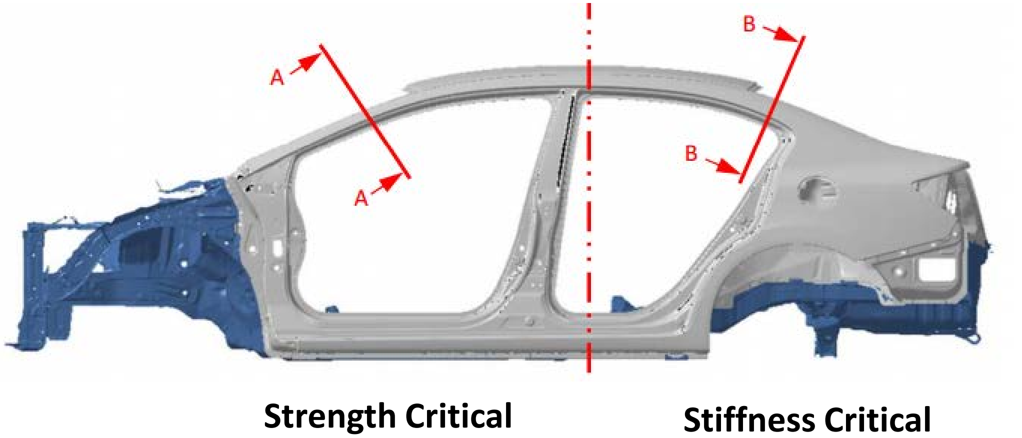
- **Objective (FY 2017-FY2018)**
  - Establish material stack-ups, configurations and joint evaluation criteria in association with partnering OEM and material supplier.
  - Perform baseline Friction Stir Lap welding (FSLW) process development and investigate welding window to produce effective joining between selected substrates.

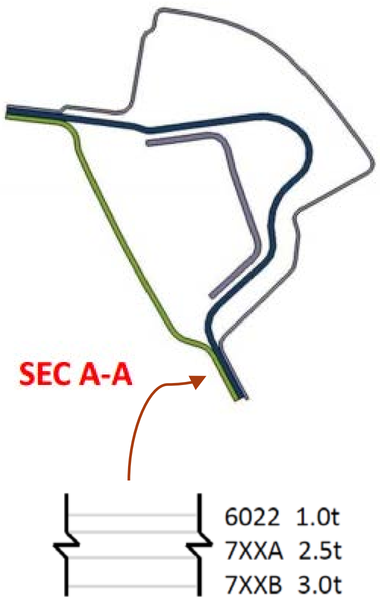
- **Impact**
  - Joining technology developed and transferred in this project will enable automotive lightweighting.
  - By increasing the welding speed up to industrial viability, we are maturing a laboratory developed solid phase processing technology for commercialization.

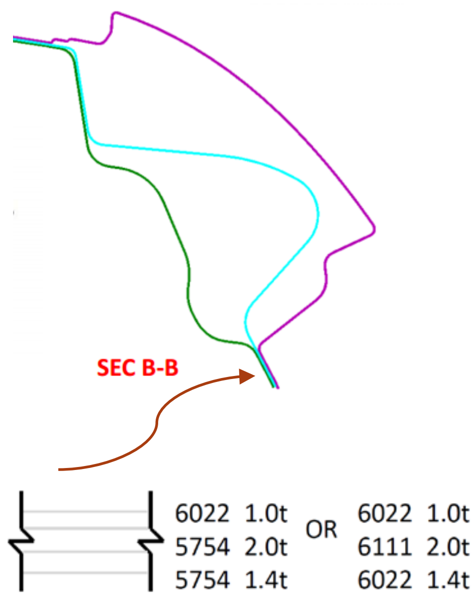
[1]US DRIVE Materials tech team Road Map, 2017, US DOE/VTO

Relevance: Target Application

Future Sedan Structure
(Aluminum Cabin on a Steel Platform)







The target is to integrate stamped Al alloys within the existing body construction, so that a function specific Al assembly can be tailored based on specific property needs.

Schedule and Progress

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		FY-17	FY2018				FY2019		
	Quarter	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**
	1.1. Material configurations & combinations								
FY18	**Milestone 1**		*						
	1.2. Weld development								
	1.3. Baseline Joint characterization								
FY18	**Milestone 2**					*			
	1.4 Near trim edge weld line sensitivity study								
	1.5 Analysis of process factors and outcomes:								
FY18	**Milestone 3**						*		
	Decision Gate: Joint Performance								
	2.1 Extended material combinations								
	2.2. FSLW tool optimization								
	3.1 Prototype design								
FY19	**Milestone 4**							*	
	3.2. Technology Transfer								

Project Milestones

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- **Milestone 1 (Q2):** Specific material combinations and configurations including sheet thicknesses and temper are finalized. Testing requirements are finalized for joint assessment for the remainder of the project. (Complete)
- **Milestone2 (Q5):** By the end of task 1.3 welding parameters are down selected on the basis of testing matrix established in Milestone 1, such that effective joints are obtained with welding speed greater than 1.0m/min. (Milestone achieved for 5754 Material set, working on 7055 Material set)
- ***Milestone 3 (Q6):*** Sensitivity study for weld line near the trim edge is complete. Analysis of process factors and joint outcomes is completed. (First set of results obtained)
- **Milestone 4 (Q7):** Prototype design is complete. FSLW tool optimization for joints developed in the project is complete.

Technical Approach

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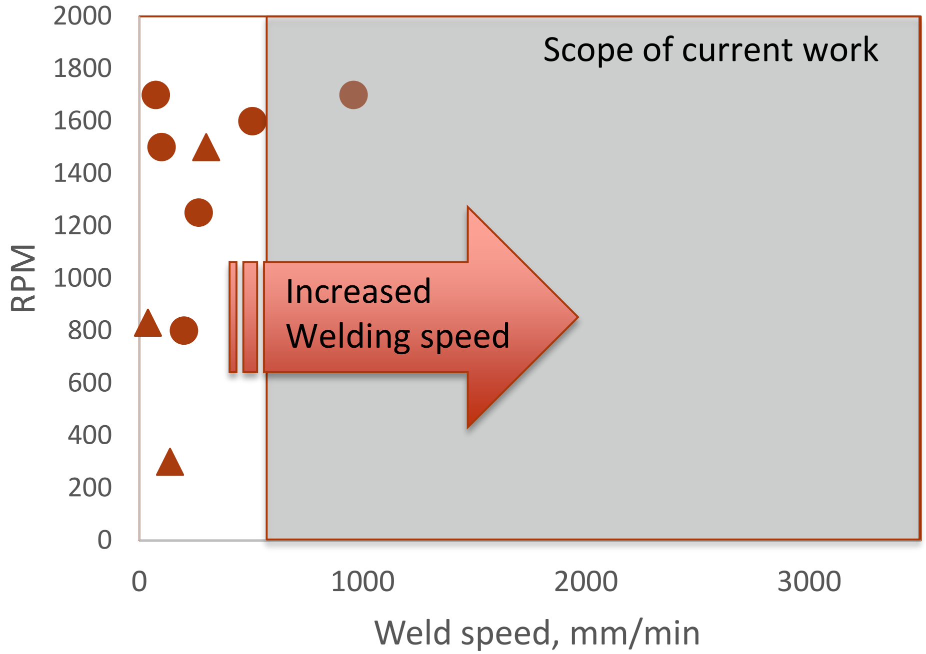
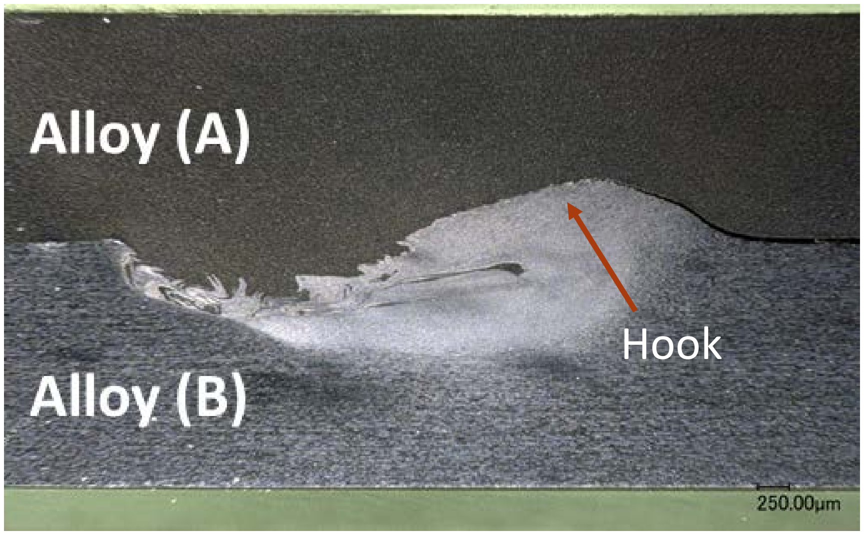
The project utilizes Friction stir welding method at high speed (welding speed ≥500mm/min) for Al alloys assembly.



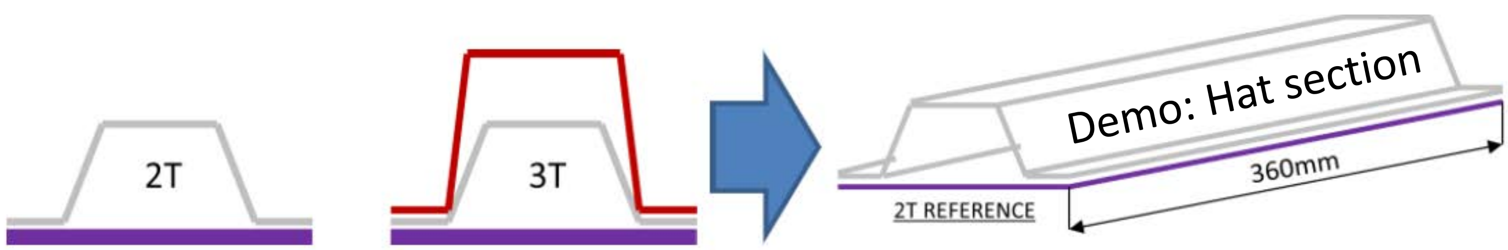


Different welding speeds for FSLW reported in the literature vs. scope of this work.

The approach is to establish welding parameters that can minimize interface hooking (upturn) and eliminate weld defect at high speed.

Technical Approach: Task Flow

- Task 1: Material Stack-up and Baseline development
  - Task 1.1.Materials and Configurations
  - Task 1.2.Weld development
  - Task 1.3 Baseline Characterization
- Task 2: Extended weld development & interface characterization
  - Task 2.1 Material variations
  - Task 2.2 FSLW tool Optimization (Design of Experiments approach)
  - Task 2.3 Comprehensive Weld assessment.
- Task 3: Prototype development and demonstration
  - Task 3.1 Prototype design
  - Task 3.2 Technology transfer



Technical Approach: Welding strategies

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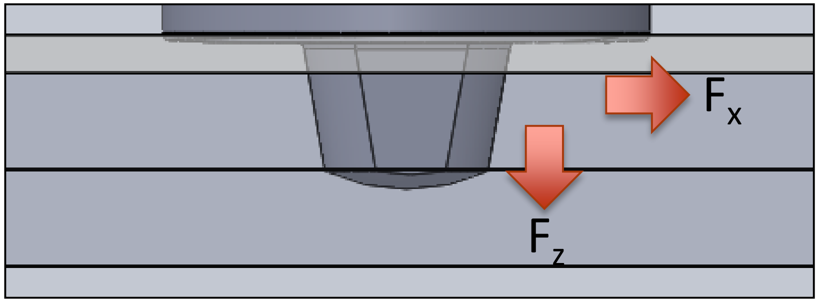
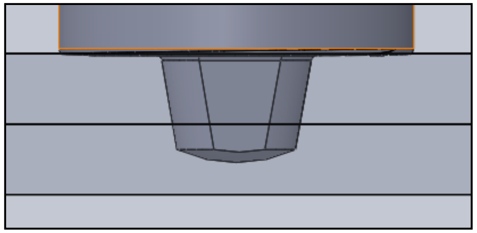
Method 1: Thin sheet on top



Pros: Single step.
Cons : Thin sheet residual stresses, chances of sheet tearing, Needs longer pin, greater F_x than Method 2.

Method 2: Two step approach



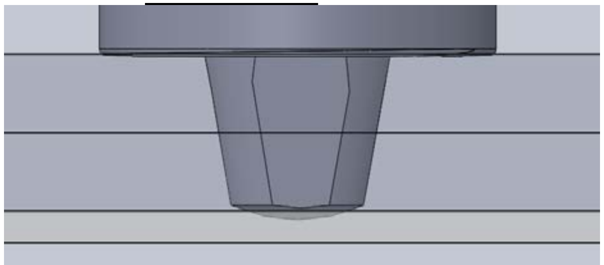
Step 1

Step 2

Pros: Shorter pin, simple setting up
Cons : Two steps, two tools

Currently focused on this approach for stack 1 (6022-7055-7055) and stack 2 (6022-5754-5754)

Method 3: Thick sheet



Pros: Single Step, no surface changes on the thin outer layer.
Cons : Longer Pin, Largest F_x, Two thick sheets disturbed by the pin completely.

Technical accomplishments: FSLW microstructure and correlation

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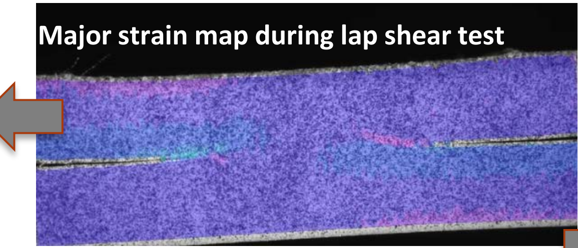
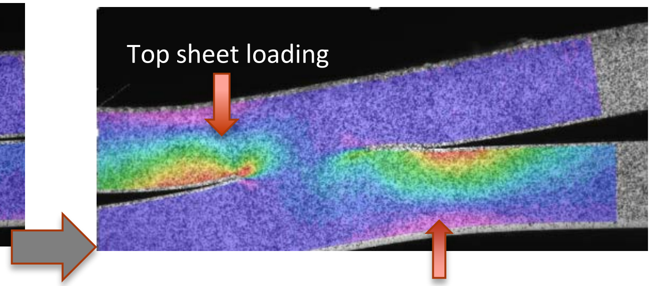
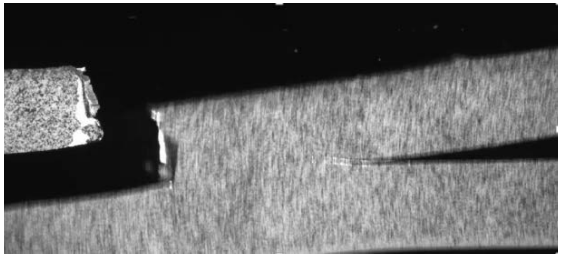
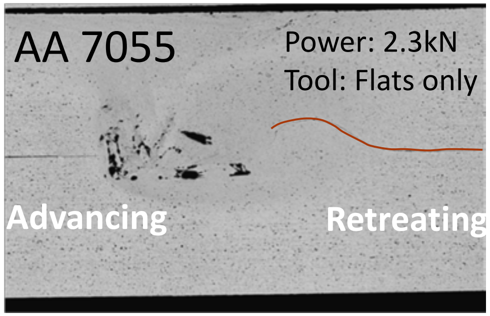
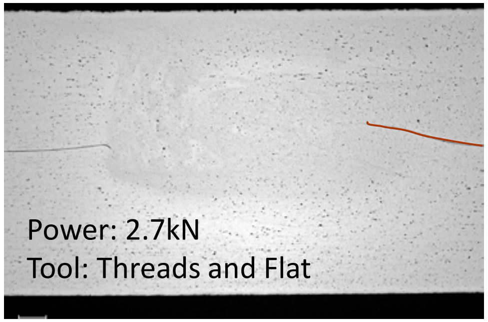
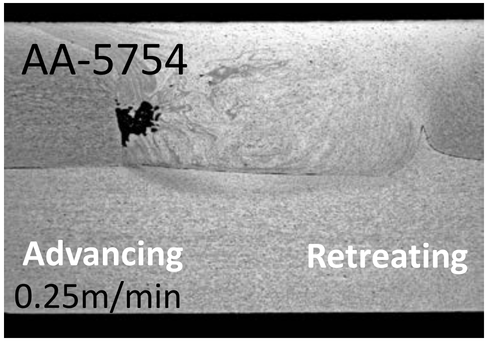


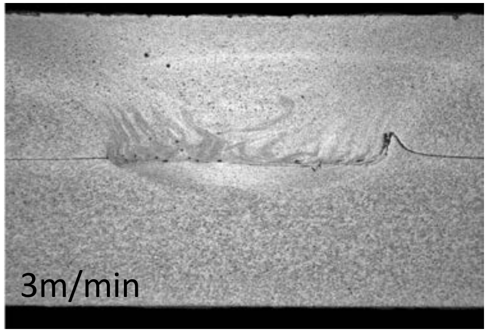






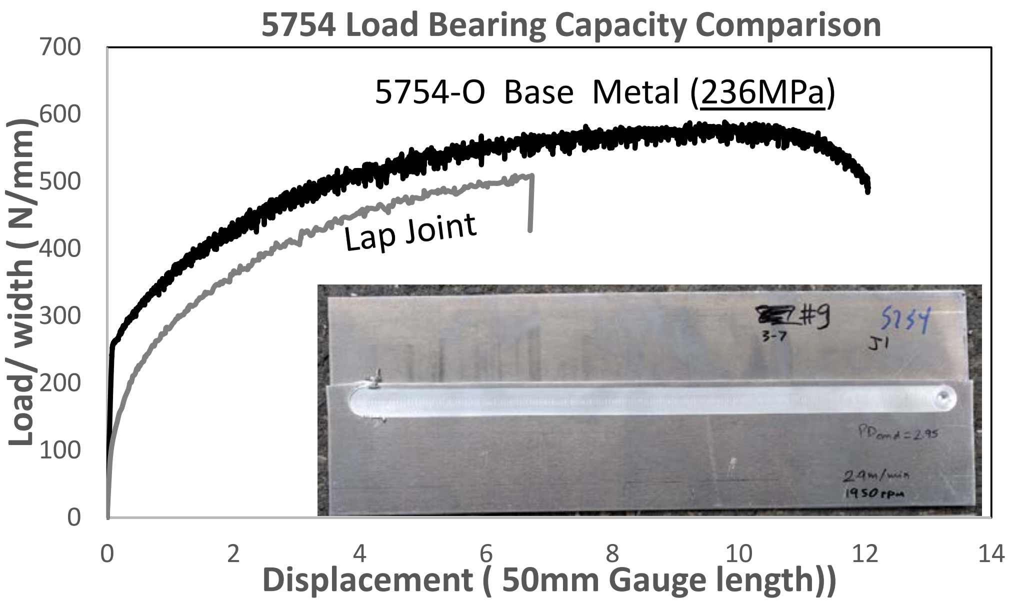


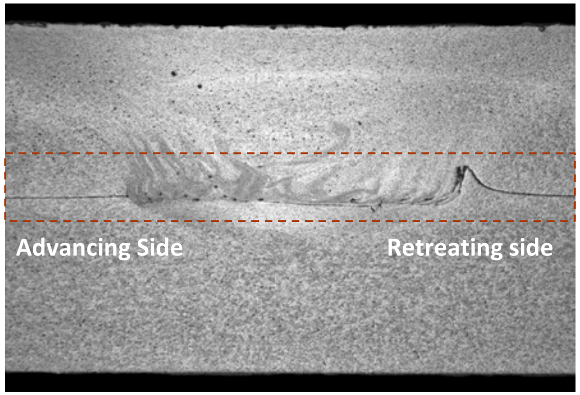


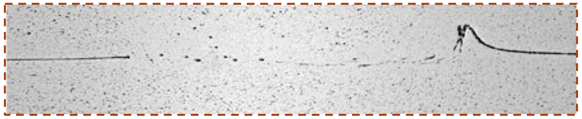


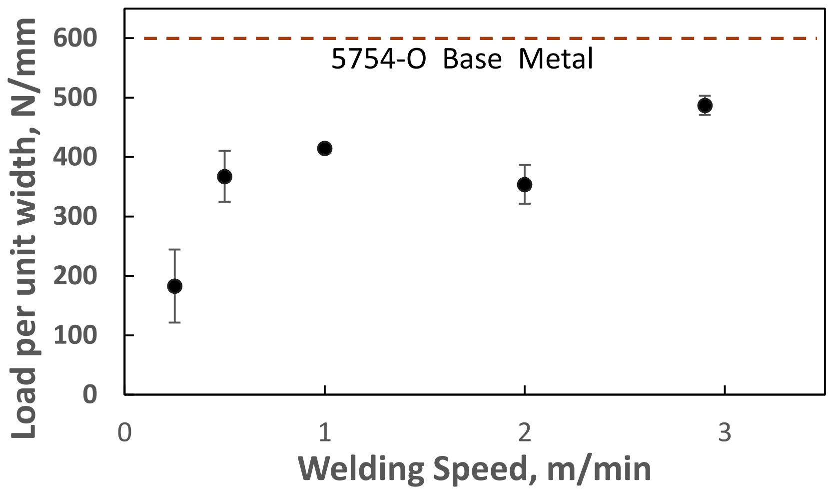
- Upturn/ hook at the interface region (specially at the retreating side) significantly effects the joint performance.
- Worm-hole types defects near the root region on Advancing side.
- Greater heat input may not always be beneficial. For 5754 material Adv. side worm-hole defect at the root was observed at lower welding speed.

Technical accomplishments: 5754 (2.5mm- 2.5mm) FSLW



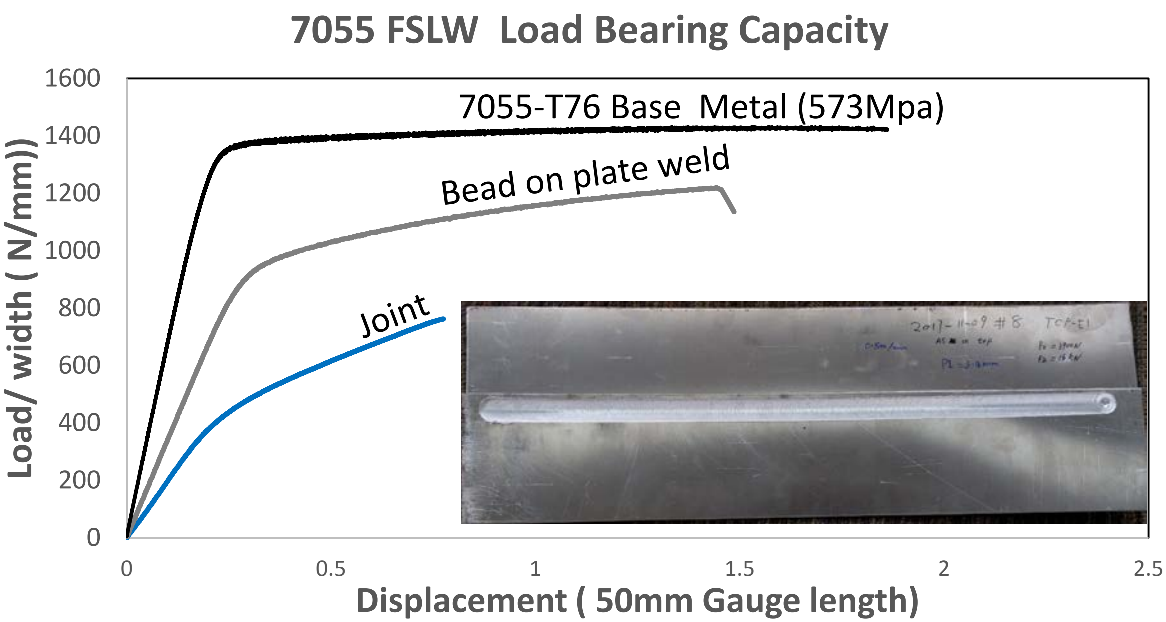


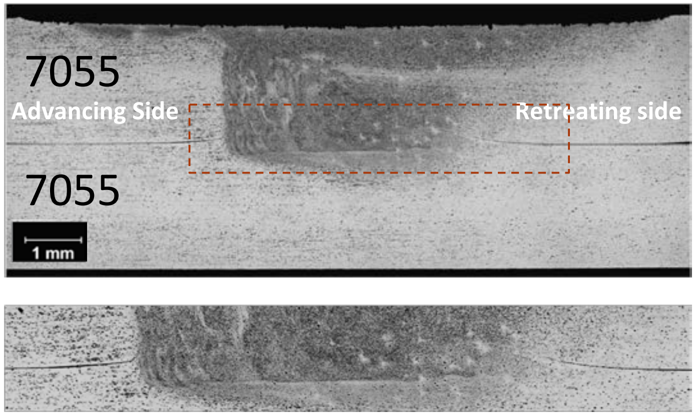




- Demonstrated a joint strength of <u>~84%±1.5% </u>of base material at a welding speed of 3 m/min. [Target Milestone 2 set at 50% with 1.5m/min]
- Energy absorption (ductility) of the joint is also fairly high (~60% of Base Material)

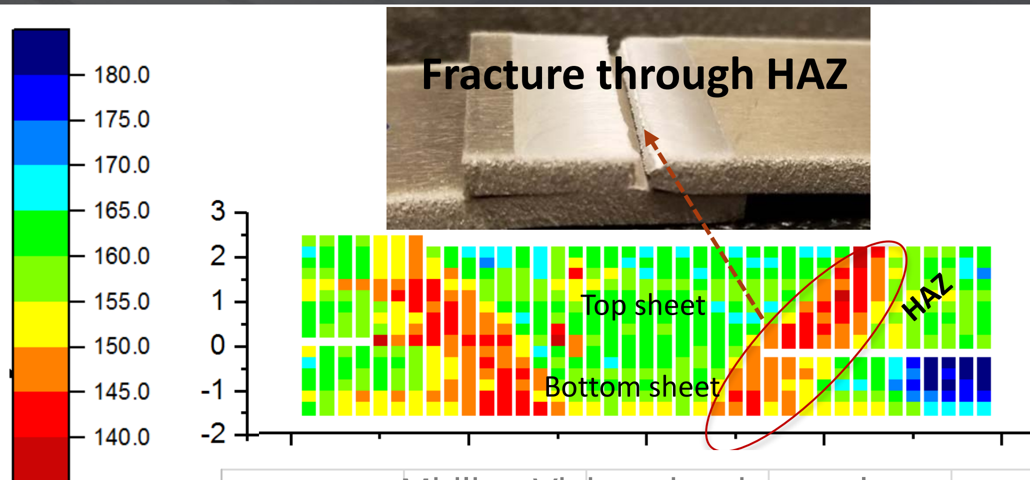
Technical accomplishments: 7055 FSLW



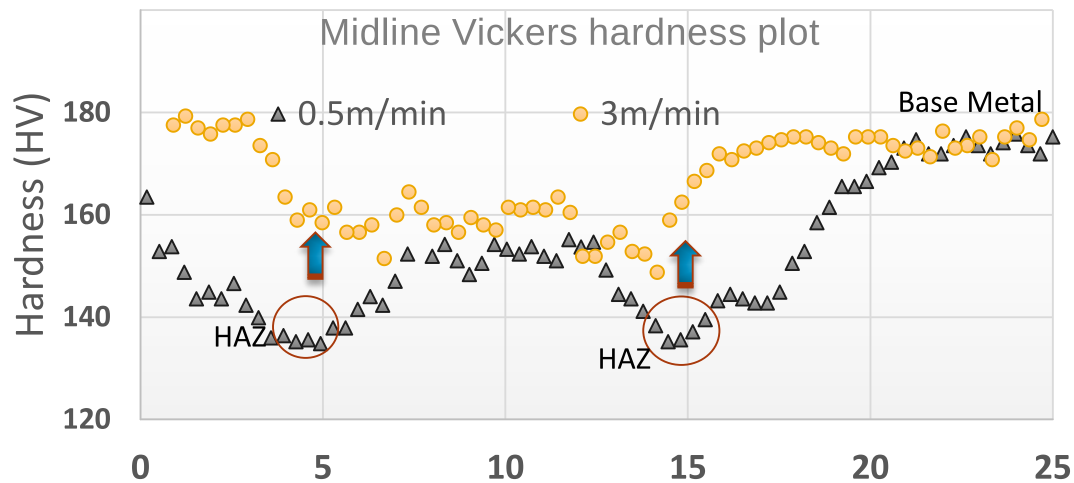


- Demonstrated a joint strength of 49±5% of base 7055 at <u>0.5m/min</u> of welding speed.
- Joints with advancing side loaded top sheet performed better than retreating side loaded top sheet. Strain distribution captured during tests shows management of hook upturn is critical. Keep top sheet loaded on the advancing side.

Accomplishments: Fractures at HAZ and welding speed effects



Weld fracture initiates at the Heat affected Zone (HAZ) minimum hardness location at the weld seam as seen in the hardness color map.



- At a greater welding speed (3m/min), the heat affected zone recovers from a significant drop in the hardness observed at 0.5m/min.
- Increased welding speed is expected to result in increased joint strength thus addressing an identified technical barrier.

Technical accomplishments: DOE based FSLW optimization

Weld ID	Speed	RPM	Pin length (mm)	Pin Angle	Tip Radius (mm)	Loading	Strength N/mm)
10-31 #2	500	1200	4.0	5	5	Adv	540±16
10-31 #3	1000	1200	4.0	5	5	Adv	391±5
10-31 #4	500	1200	4.0	0	5	Adv	641±53
10-31 #7	500	1200	4.0	10	5	Adv	369±28
10-31 #9	1000	1600	4.0	10	5	Adv	295±17
11-1 #1	500	1200	4.0	10	12	Adv	443±22
11-8 #1	500	1200	3.5	10	0	Adv	424±16
11-8 #2	500	1200	3.5	10	0	Ret	320±16
11-8 #3	1000	1950	3.5	10	0	Adv	165±12
11-8 #4	500	1200	3.1	5	0	Ret	581±45
11-9 #1	500	1200	3.1	5	0	Adv	566±27
11-9 #2	1000	1950	3.1	5	0	Ret	372±11
11-9 #4	500	1200	3.4	5	0	Ret	466±16
11-9 #5	500	1200	3.3	10	0	Ret	351±11
11-9 #6	500	1200	3.1	10	0	Ret	561±29
11-9 #7	500	1200	3.4	10	0	Ret	505±8
11-9 #8	500	1200	3.4	10	0	Adv	691±34

- We ran a series of FSLW optimization study to understand effects of tool features and welding parameters on joint microstructure and strength.

Technical Accomplishment:
Effects of welding parameters on joint strength

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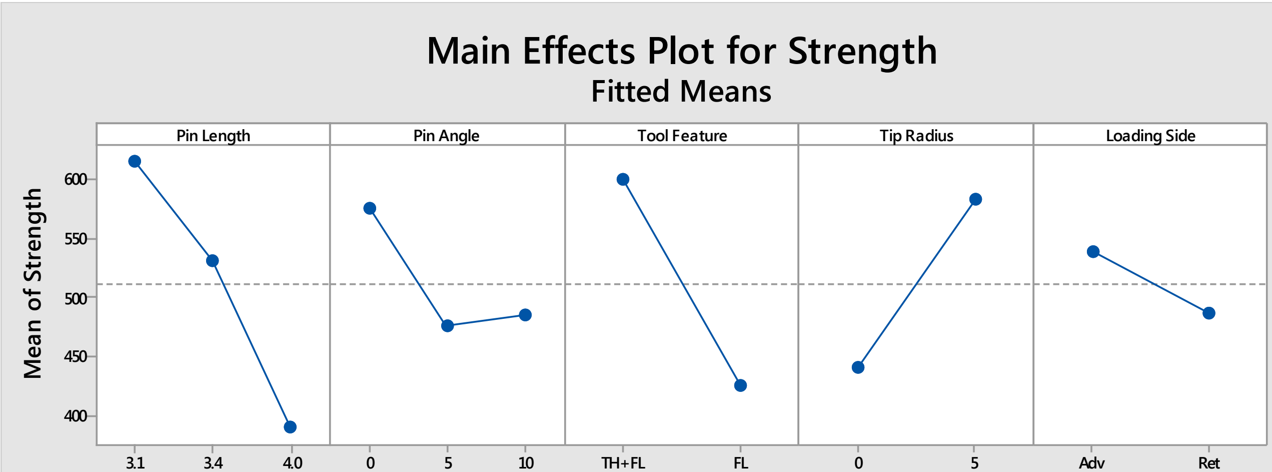

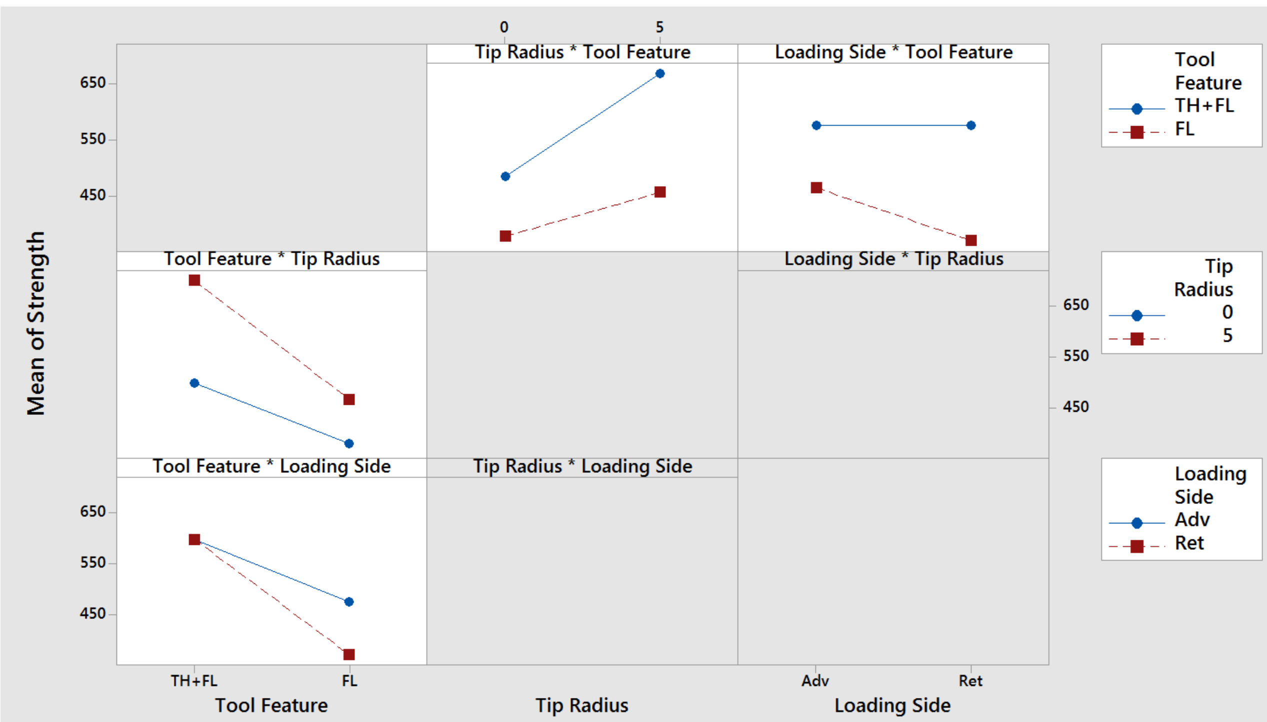

- Initial DOE based optimization run showed that pin angle, pin tip radius and pin features are important factors.
- For a 2.5mm top sheet, a pin length of 3.1mm provided highest strength.
- Advancing side loaded top sheet FSLW performed better
- Radiused tool performed better than a flat pin design.

Response to Reviewer Comments

This project is being reported for the first time.

Collaboration and coordination

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- We have regular conference calls between partners where project work scope and tasks are discussed.
- Through the in-kind funds available to partners
  - Honda
    - Provides assessments on production relevance of material stack up and configurations
    - Provides input on joint evaluation/ characterization matrix and test requirements.
    - Leads on prototype design and evaluation metric and testing.
  - Arconic
    - Provides relevant Aluminum alloys
    - Provides relevant material dataset

Remaining Challenges and Barriers

- Meeting and exceeding the target strength requirements for 7xxx series FSLW.
- Increasing the welding speed of FSLW for 7xxx Al alloys.
  - Currently at greater welding speeds, we observe advancing side worm whole defects, and crown surface defects.
- Integration of third Al outer layer into the FSLW joints
- The process needs to demonstrate joining of third thin layer of 6xxx Al alloy with superior surface finish.
- Drawbacks of welding near the trim edge is unknown.

Planned Future Work

- Complete next round of FSLW optimization study for 7xxx and 5xxx series alloys [Milestone 2]
  - This will include tools with larger shoulder diameters and aggressive pins for reaching target strength requirements in 7xxx series stack-ups.
- Complete edge sensitivity study with all the material stack up [Milestone 3]
  - Hardness, lap shear and peel testing data will be used to evaluate edge sensitivity of FSLW.
- Process development for 6xxx series FSLW as a part of Task 2.
- Establish parameters for joining thin outer sheet to main joint. We will evaluate all 3 methods outlined in Slide 9.
- Initiate technology transfer activities to partners.[Milestone 4]

Any proposed future work is subject to change based on funding levels.

Project Summary

The goal of this project is to develop FSLW such that viable joints in several Al alloys can be made at industrially viable welding speed for commercialization.

- This project develops an emerging solid state joining technique with potential to fabricate Al assembly such that
  - Cost of Al alloys joining can be reduced enabling vehicle light weighting.
  - Faster assembly process can enable adoption of newer Al alloy in high volume cars

Key Technical Challenges	Accomplishments this year Results/Impact
Demonstrate joint Efficiency of 50% for FSLW.	After FSLW process optimization we established welding parameters to produce welds at 84% joint efficiency for 5754-O material.
Demonstrate high welding speed for industrial viability	Effective joints were made at 3m/min welding speed for AA5754 material stack-up.

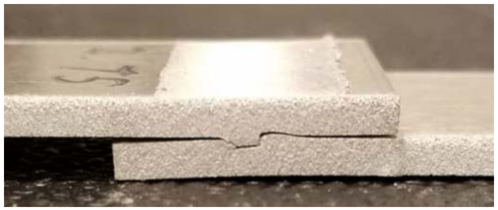
Milestones and Deliverables coming up and Future work
Demonstrate 50% or greater joint efficiency for AA7055 FSLW.
Determine and mitigate challenges to use FSLW as close to trim edge as practicable.
Provide FSLW samples for characterization and testing to Honda.
Technology transfer to Honda.

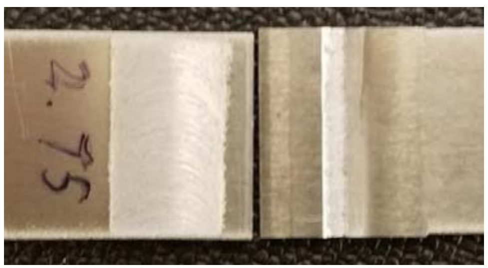
Any proposed future work is subject to change based on funding levels.

Technical Back-Up Slides

Fracture types

Interfacial Fracture



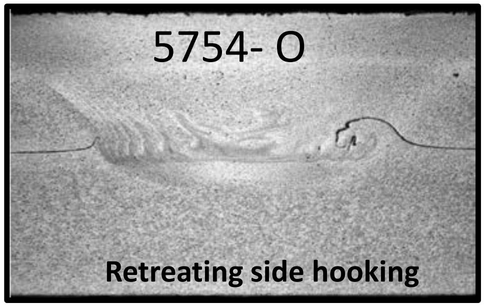


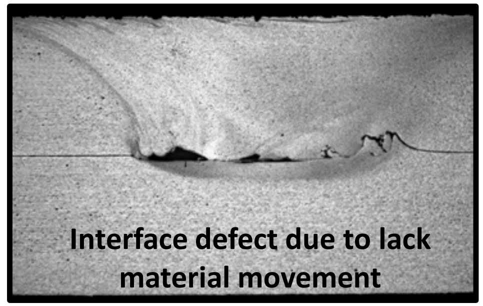
Fracture through HAZ (top sheet)

Fracture through HAZ (Bottom sheet)

Defect Types

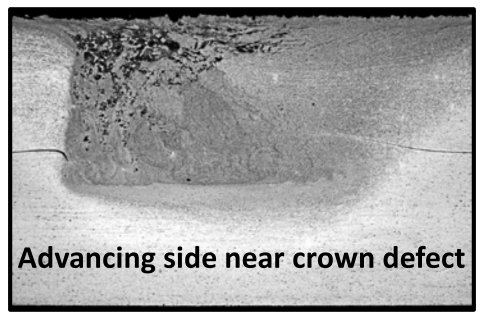
Cross-sections

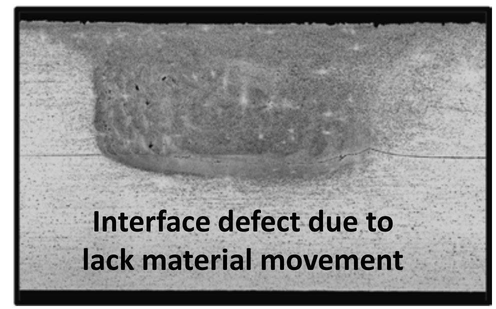

5754- O
Retreating side hooking


Interface defect due to lack material movement


Advancing side wormhole defect


7055- T76
Advancing side worm hole


Advancing side near crown defect


Interface defect due to lack material movement

Crown Surfaces

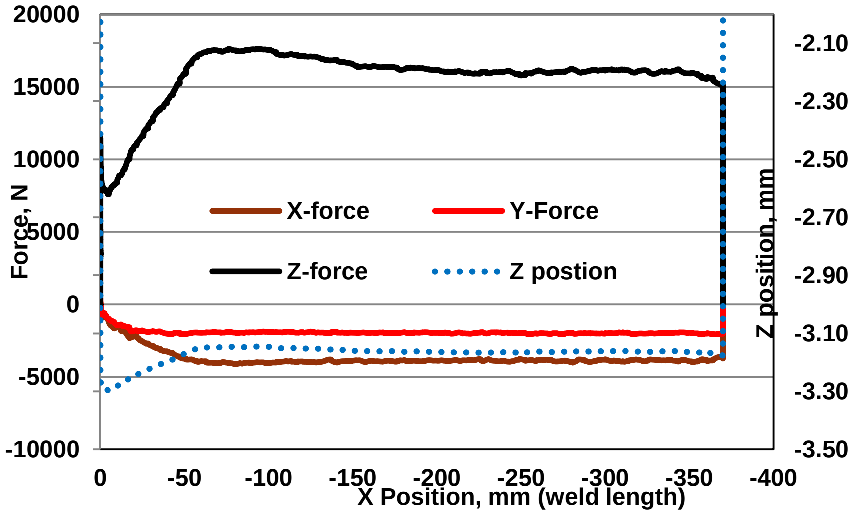

Smooth surface

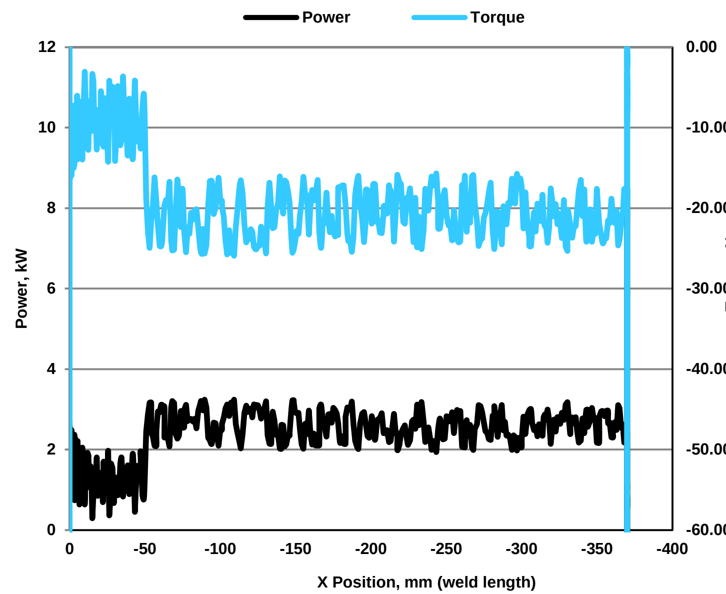

Surface Incipient melting in 7xxx series


Excessive flash caused by non-ideal plunge depth

Force and position data acquired during welding

AA7055(2.55mm)- AA7055 (2.5mm)





Force signature and z position after initial startup is relatively stable. Data such as this is critical in design of robotic and gantry type systems for commercialization.

Planned DOE approach (tool geometry variations)

↓	C1	C2-T	C3	C4
	Pin Length	Pin Feature	Pin Angle	Pin Radius
1	3.1	TH	0	0
2	3.1	FL+TH	5	0
3	3.1	STH+FL	10	5
4	3.1	STH+FL	0	5
5	3.4	TH	5	5
6	3.4	FL+TH	0	5
7	3.4	STH+FL	0	0
8	3.4	STH+FL	10	0
9	3.7	TH	10	0
10	3.7	FL+TH	0	0
11	3.7	STH+FL	0	5
12	3.7	STH+FL	5	5
13	4.0	TH	0	5
14	4.0	FL+TH	10	5
15	4.0	STH+FL	5	0
16	4.0	STH+FL	0	0

Any proposed future work is subject to change based on funding levels.